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PROBLEMS AND DIRECTIONS FOR LARGE SCALE
GEOGRAPHIC INFORMATION SYSTEM DEVELOPMENT
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**Review and Synthesis of Problems and Directions
for Large Scale Geographic Information System Development**

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NASA

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for Large Scale Geographic Information System Development**

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EXECUTIVE SUMMARY

INTRODUCTION

A conference was held in Palm Springs, California on April 11-14, 1983 to review and synthesize problems and directions for large scale geographic information system development and to deal with the general problems associated with automated geographic information systems and spatial data handling.

The conference came about after informal discussions over a period of several years between the five participants (Dr. Ray Boyle, Mr. Jack Dangermond, Dr. Duane Marble, Dr. David Simonett, and Dr. Roger Tomlinson).

The conference was designed to permit free-wheeling discussion of the topic with perhaps a twenty year time frame in mind for solving the problems identified.

This report has been extracted from that discussion, with editing.

The subjects in the CONFERENCE RESULTS are quite diverse and are grouped into ten headings for the sake of convenience. For each topic a problem or subject is given, then there is a brief analysis of the topic, and then brief recommendations are presented.

The substance of the problem and recommendations statements are in this EXECUTIVE SUMMARY.

OPENING DISCUSSION

In undertaking the conference discussions, the participants assumed that it is better to monitor events than not, better to plan than await events, better to make policies than drift, better to make decisions than avoid them and better to manage affairs than to avoid problems. Automated Geographic Information Systems (AGIS's) are useful in doing all these things.

AGIS's have numerous advantages, in comparison with manual methods of using geographic data. They save money, time, and other resources; they provide better products in a more timely way; they provide powerful tools of analysis and clear and attractive displays of data.

Moreover there are many world trends leading to their increased use: increases in the needs of the world's people, increases in the quality and quantity of the technology AGIS's depend on; and increased awareness of the value of these systems.

AGIS's could be applied to a number of world problems, but this would require the creation of very large or even global data bases.

The creation and use of such data bases would require the solution of a number of problems, discussions of which follow here.

TOPICS DISCUSSED

THEORY

Spatial Relations Theory. There is at present no coherent mathematical theory of spatial relations. A small group of knowledgeable persons should be selected to define the problem thus created. Then a group of mathematicians should be selected to meet and refine the problem statement and to identify what means are best adapted to its solution. Research in the area should be funded and encouraged in such a way that significant progress might be made within about a ten year period. Development and engineering implementation of the results of this research should be promptly supported.

APPLIED SCIENCE

Artificial Intelligence. Important, perhaps revolutionary developments will occur in artificial intelligence in the next twenty years and will probably have AGIS applications. The developments should be watched closely by the AGIS field and applied to AGIS technology as promptly as possible. Interdisciplinary research institutes should be set up to insure that artificial intelligence is integrated into AGIS's within a broad interdisciplinary and total system development context.

Expert Systems. Expert systems which include AGIS capabilities are likely to attract new users to the AGIS field. The development of expert systems helpful to AGIS users should be encouraged. Artificial intelligence should be incorporated into such systems as it becomes practical.

Data Aggregation and Generalization. The need to aggregate and generalize data is a continuing technical problem in AGIS's and it is made more severe as data bases grow larger and approach global coverage. Continuing research and development attention needs to be paid to these problems, and practical pilot efforts with solutions need to be attempted.

Exploratory Data Analysis. As data bases become ever larger it is important to be able to use AGIS's to explore them efficiently. Methods and algorithms for exploratory data analysis and for data base browsing need to be further developed.

Data Base Queries. It is extremely difficult to query large data bases, but it is extremely important to be able to do so and do so efficiently and even quickly. Research and development in this area is especially important for the creation and use of very large or global data bases, and needs to be supported.

ENGINEERING AND TECHNOLOGY

Global Data Bases. A series of concerns must be addressed if successful global data bases are to be created for wide public use. A variety of problems dealing with creating a global data base will need to be addressed simultaneously if progress is to be made. Pilot studies of global data bases need to be undertaken.

Improved Data Automation. Data automation is probably the biggest bottleneck in AGIS function at present and represents the greatest single cost in most projects, especially where the data base is very large. Research and development in this area should have the highest priority. Research and development in a number of related areas may need to be done before progress in automation can be significant; these areas probably include feature recognition, cognitive science, artificial intelligence and others. Documentation of present methods, costs and throughputs needs to be obtained to provide baseline data against which potential improvements can be measured.

Data Editing. Data editing functions of AGIS's need to be greatly improved, especially as data volumes increase. Continuing research and development of automated editing is needed. The use of artificial intelligence in support of such editing should be examined closely.

Data Updating. Improved methods for updating data in data bases are needed. Continuing development of updating methods is of great importance to the integrity of data bases and to the maintenance of user confidence in AGIS's.

Economics of AGIS Use. More agencies would use AGIS technology if they had better information about the cost/benefit ratios and the economics of AGIS applications. Economic and throughput analyses of AGIS functions are important to the development of the field, and the performance of such analyses and the publication of their results needs to be encouraged.

Benchmarking. Benchmark tests would probably be useful in measuring the performance of a wider variety of AGIS functions, and should probably be more widely used in selecting systems. Persons expert in the design and conduct of benchmark tests should be urged to share this knowledge. Some publication of benchmark results would be useful to potential system users, if accompanied with appropriate cautionary remarks.

Case Studies. Use of AGIS's is inhibited in many cases because of a lack of reliable information about what such use entails in terms of time, cost, personnel and other resources, and a lack of information about the course of events which application of AGIS's requires. Documentation of uses of AGIS's in the form of case studies should be encouraged. If at all possible, third parties should carry out these case studies in order to ensure greater objectivity in the studies. Steps should be taken to ensure the wide distribution and availability of these case studies. Funding (estimated at about 3% of total project cost) should probably be included in AGIS project budgets to ensure that documentation of the projects is performed so that case studies can be carried out.

Documentation of Applications. It is important that potential users be aware of what it takes to apply AGIS technology to their particular problems, what models exist which may apply to their needs, and what successful applications like their have already been done. Efforts should be increased to obtain prompt publication and dissemination of information about successful applications, perhaps through the auspices of a professional society, clearinghouse operation, or like mechanism.

Algorithmic Analysis. Sustained and organized study of existing software needs to be undertaken and supported. Suppliers of AGIS's should be urged to cooperate with such efforts; it may be that joint research efforts involving many system vendors is possible in this limited aspect of AGIS software.

Software. Computer software development is a continuing problem in the AGIS field and limits capabilities far more than does hardware. Additional resources need to be devoted to software creation and the incentives for software creation need to be increased. If better systems for creation good software can be devised, they deserve support and encouragement.

Computer Hardware. The needs of AGIS's for hardware will probably be met chiefly due to marketplace pressures now leading to rapid advancement in hardware capabilities and rapid declines in cost; nevertheless, some improved hardware capabilities would be valuable to the AGIS field. In special cases, where AGIS's are the chief user of some hardware devices, special efforts may be needed to obtain the capabilities required, since market forces may not otherwise lead to their being created. AGIS system designers need to rapidly integrate new hardware capabilities into their systems if the needs of very large or global data bases are to be met.

Ergonomics. Although the theory underlying ergonomics is not mature, ergonomic studies are important if AGIS's are to be made more useful and efficient. Ergonomics must be put on a sound basis and then applied rigorously to AGIS technology. When ergonomically sound systems are designed, they need to be promptly implemented in production models.

AGIS Standards. The use of standards for AGIS's involves important choices, and both benefits and problems. Continuing attention to the question of standards is appropriate, especially as global data bases are created. This is another matter in which cooperative efforts and professional organizations might play a useful role.

Geographic Referencing Systems. Geographic referencing systems may have to be reexamined in light of AGIS use and the creation of global data bases. Developments in the theory of spatial relations, in AGIS's and in schema for a global data base may all influence the choice of a referencing system for a global data base, and all should be considered as this choice is made.

User Friendliness. AGIS's need to be user friendly. Serious (as opposed to cosmetic) attempts at creating user friendly AGIS's need to be continued, using the best guidance available from a wide range of fields, such as ergonomics, cognitive science, etc.

Need for Improved Efficiencies. There is a need for improved efficiencies in nearly every aspect of AGIS function. Efforts in software development, algorithmic analysis, data base structure design, ergonomics, engineering economics and a whole range of other areas are needed in order to achieve improved efficiencies in AGIS function.

INSTITUTIONS

NAS/NRC Definitive Study. A neutral, competent and respected body needs to examine the field of automated spatial and geographic information systems and prepare an evaluation of the problems and promise associated with it. A National Academy of Sciences/National Research Council "definitive study" of the field should be made. Federal agencies should be approached and interested in such a study and from among them a lead agency should be found. Funding for the study needs to be solicited from a number of federal agencies.

Archival Storage of Data. A problem of pressing importance is the need for archival storage of imagery and data already gathered. Immediate intense effort needs to be made to secure the archiving of the irreplaceable data and imagery we have already gathered. Longer range efforts need to be made to provide for archiving facilities. Everyone involved in gathering or using these data needs to be supportive and cooperative with this effort.

Improved Communication. Communication between persons within the AGIS field and between the field and persons and organizations outside the field need to be greatly improved. A wide variety of communication means needs to be adopted and concerted efforts need to be made to make communication more effective and frequent, within the field and with those outside it.

Technology Transfer and Diffusion. The transfer and diffusion of AGIS technology to new users, especially in the developing world, is important. Continuing attention needs to be paid to this problem and successful methods for promoting transfer and diffusion need to be found and more widely used.

Seeing AGIS As A Discipline. The study and use of automated geographic information systems and of spatial data systems should be considered as a discipline or field of study rather than just the application of a technology. Continuing efforts are needed to foster this perception and support it with concrete actions.

A Society for Spatial Information Systems. To promote various disciplinary and professional goals and activities, a professional society dealing with the AGIS field and related areas is needed. Steps should be taken to found a professional society dealing with spatial information.

1984 Meeting in Zurich, Switzerland. In order to promote development in the AGIS field and closely related fields, an early international meeting should be held. An international meeting on spatial data handling and related matters should be held in Zurich, Switzerland in 1984. Persons active in AGIS work and related fields should be encouraged to attend and supported financially where possible.

Supportive Environment. If the AGIS field is to develop rapidly a more supportive environment will be needed for those working in the field. This support will need to be created, planned for and fostered on a continuing basis, and the efforts will have to be well led.

Institutions Needed. A variety of specific institutions will be needed if the AGIS field is to grow and meet the demands which will be placed on it. Those in the field will have to plan for, create and support such institutions on a continuing basis.

AGIS Education. Improved education and training for working with AGIS's is needed and more students need to be prepared for the field. Additional graduate programs, especially at the Masters level, are needed. Curricula need improvement and model curricula should be devised and publicized. A variety of other educational and training opportunities are needed for refreshing and retraining those in the field and for training potential users of the technology. Equipment and software need to be provided for such programs; government and industry might cooperate to help meet these needs.

Research Institutions. Not enough research is going on in the AGIS field. More support needs to be provided for research in the field. Centers of excellence, devoted to research on automated geographic and automated spatial information systems, need to be created and supported on a long term basis.

Decision Making Institutions. The use of AGIS technology could be usefully integrated into the decision making processes of many institutions where it is not now employed. Continuing efforts need to be made to make decision makers aware of the usefulness of AGIS's in decision making and related processes. Continuing studies need to be made of the best way of integrating AGIS's into decision making, and successes need to be made widely known.

Roles of Federal Agencies. Federal agencies have important roles to play in the development of the AGIS field. Work should begin in a concerted way to obtain agency support for developing the AGIS field. Agencies which are interested should be identified, to include the names of specific persons. Sources of funds, ongoing related projects, future agency plans, and other important information should be gathered. These efforts need to be coordinated and useful information needs to be exchanged among those working in this direction.

University/Industry/Government Cooperation. No single sector of the economy has the means to provide all the support needed for the development of AGIS technology; cooperation among the sectors will be required. Continuing efforts should be made to foster cooperation between government, industry and the universities in support of the development of the AGIS field.

System Implementation. AGIS's which meet all of a user's technical requirements may yet fail because of a poor implementation process. In developing AGIS's it is extremely important that system implementation receive careful attention and all resources needed to make it successful.

People Problems and Political Problems. The creation and use of AGIS's inevitably result in situations from which problems can arise, problems which are people centered as opposed to technical and political problems. Those responsible for making policy about AGIS's, decision makers generally, and those installing and using AGIS's need to be aware of these potential problems and devote the needed resources to ameliorating them.

Pricing and Profits in the AGIS Field. Both private industry and government have some influence on pricing in the AGIS field and the influence of their actions will determine how rapidly some facets of AGIS technology will develop. Where private industry is not developing needed AGIS technology which is important to the public good, the government should consider supporting research and development by various means available to it. Government may also need to continue support in ways which keep prices low enough to encourage adoption of this technology by users who could not afford the "real" costs of the technology.

System Linkages. Better linkages are needed between various kinds of data in a single data base, between different components of single systems, and between different systems; data sharing agreements need continuing encouragement. Systems vendors, users, government and professional organizations need to continue to work toward agreements and technological solutions to making more effective linkages possible.

Consultants. Experienced consultants are needed in the AGIS field and there may not be enough competent consultants available to meet the anticipated future growth in the field. In the absence of sufficient competent consultants a wide range of educational and communication efforts need to be undertaken to ensure that reliable information about the field is widely available.

RESUMES OF THE PARTICIPANTS

Resumes of the participants in the conference are included in the final part of this report.

SPECIFIC RECOMMENDATIONS TO NASA

As a result of the conference discussions the following specific and immediate recommendations for NASA actions are presented:

1. That NASA take the lead in arranging for and funding a "definitive study" of the field of spatial data handling, spatial information systems and automated geographic information system technology, the study to be under the auspices of the National Academy of Sciences/National Research Council.
2. That NASA support and fund a series of additional small conferences over the next few years to better define and obtain consensus about what needs to be done to insure prompt development in this field.
3. That NASA join with other agencies in funding the planning for and conduct of an international conference in this field to be held in 1984-85.
4. That NASA join with other agencies in funding research in certain critical areas in the field, such as research leading to a coherent theory of spatial relations.
5. That NASA join with other agencies, perhaps international agencies such as those of the U.N., to determine the functional requirements that users would have for a global geographic information data base and system.
6. That NASA support and fund a "centers of excellence" program in which a few select academic institutions are assisted in further developing their research and teaching programs in spatial data handling, automated geographic information systems and related areas.

ACKNOWLEDGEMENTS

This report and the conference on which it is based were supported by NASA contract NAS2-11346 for Review and Synthesis of Problems and Directions for Large Scale Geographic Information System Development, awarded to Environmental Systems Research Institute.

Extensive typing of material used in preparing this report was done by Lila Blanchard.

INTRODUCTION

Subject of this Report

This is the final report of a conference held to review and synthesize problems and directions for large scale geographic information system development, and to deal with the general problems associated with automated geographic information systems and spatial data handling.

Background to the Conference

The conference came about as a result of informal discussions among the five conference participants over a period of several years preceding the conference itself. These discussions suggested that there was a need to consider the problems of very large spatial data bases since such data bases were beginning to be created and since the United Nations, NASA and other organizations were considering the creation of very large and even global data bases.

As a result of these informal discussions a proposal was submitted to NASA asking for its support for about a four day meeting of a small group which would take up these issues and report on them in written form.

NASA agreed to the proposal.

The Conference

The conference was held in Palm Springs, California on April 11-14, 1983.

The five participants were Dr. Ray Boyle, Mr. Jack Dangermond, Dr. Duane Marble, Dr. David Simonett and Dr. Roger Tomlinson. Dr. Kent Smith, who is the editor of this report, was also present. (Resumes of the participants are included in an appendix to this report.)

The format of the conference was designed to bring together this small group of persons with extensive knowledge and experience in the field of automated geographic information systems and large scale data bases, and permit them to discuss, rather freely, their individual and group perceptions of the field, its problems and the direction it ought to take; in looking ahead, a twenty year planning period was suggested. Beyond this general direction no initial guidance was provided, and the widest ranging discussion was encouraged.

The complete discussions were recorded for later reference use by the participants and for use in the preparation of this report.

Preparation of this Report

The editor extracted from the extensive discussion those ideas which needed to be communicated to NASA and other readers of this final report and then submitted a draft of these to the participants for their review. The topics discussed in the body of this report are the result of that effort.

Treatment of the Subjects of this Report

Because of the large number of issues touched on, the mention of each in this report is relatively brief. Because of the diversity of the topics, discussions and recommendations offered vary widely in their natures; in some cases specific suggestions for projects are offered, while in other cases only the most general direction for future effort is indicated.

This result also reflects the conviction of the participants that much needs to be done in this field and that additional conferences and meetings need to be held in order to more precisely define and concert efforts of those in the field.

Structure of this Report

Following the TITLE PAGE of this report there is an ANALYTICAL TABLE OF CONTENTS which provides for each report topic and for other sections of this report at least a one sentence summary. For the report topics this sentence is drawn from the EXECUTIVE SUMMARY.

The EXECUTIVE SUMMARY consists of an Introduction and then an account of the Conference Results, beginning with the opening discussions and going on to the individual topics discussed. For each topic the subject discussed is listed and then the recommendations made are summarized. The result is about a two sentence paragraph for each topic. This paragraph is drawn from the body of the report, using the sentences that introduce and conclude each topic discussion.

Following the EXECUTIVE SUMMARY are the SPECIFIC RECOMMENDATIONS TO NASA. This is a brief list of specific recommendations for actions which NASA might take in the near term to support the broader range of recommendations which the overall report proposes. These are briefly stated on the assumption that details would need to be worked out separately, perhaps through detailed proposals or policy papers.

ACKNOWLEDGEMENTS follow.

This INTRODUCTION comes next.

The RESULTS OF THE CONFERENCE, which follows this INTRODUCTION, begins with an account of the OPENING DISCUSSIONS which took place at the conference. These were discussions of the present situations in the world which would benefit from the use of automated geographic information systems (AGIS's) and would benefit from the creation of very large geographic data bases. Future trends which are leading in this direction are also briefly noted.

The more than forty topics which provide the bulk of this report are organized here into four categories: THEORY, APPLIED SCIENCE, ENGINEERING AND TECHNOLOGY and INSTITUTIONS. These are divisions of convenience, however, and it should be understood that the topics all relate to one another and dividing them from one another in any way is somewhat artificial.

For each of the topics under these four categories there is, first, a brief statement of the topic or issue, then a summary of the ideas mentioned at the conference which are relevant to the topic, and finally the recommendations which were offered by the conference participants. The texts in the EXECUTIVE SUMMARY are drawn directly from the issue statements and recommendations for each individual topic. The summary sentences in the ANALYTICAL TABLE OF CONTENTS are drawn from this same source, but with greater compression and simplification.

The final portion of this report is the RESUMES OF THE PARTICIPANTS which includes resumes for each of the five participants, and should provide readers with a better idea of the experiences from which the ideas and recommendations in this report have been derived.

CONFERENCE RESULTS

OPENING DISCUSSIONS

Assumptions Underlying the Discussions

There are a number of assumptions that probably underlie any discussions of automated geographic information systems and their application. These assumptions would include:

- It is better to monitor events than to not know what is going on.
- It is better plan for the future than to await events passively.
- It is better to establish sound policies than to try to do without them.
- It is better to make decisions than avoid them or let events force them.
- It is better to manage affairs than to allow them to take care of themselves.

The Roles of Automated Geographic Information Systems

Automated Geographic Information Systems (AGIS's) are useful for monitoring and reporting, planning, policy making, decision making and management--all the functions mentioned above.

The Advantages of Using AGIS's

In comparison with manual methods of applying geographic information to these tasks, AGIS's offer many advantages.

They allow the storage in a readily retrievable form of many kinds of data, including geographically referenced data, and they insure that the data are not lost or forgotten about.

By processing the data under computer control, AGIS's allow these data to be incorporated into decision making in situations where, if only manual methods were used, the data would have to be overlooked because of a lack of time, because of the high costs of processing them, or because of a lack of trained staff needed to deal with them effectively.

They permit the data to be readily updated so that decision makers can have confidence in the data base and be certain they are using the most current information available.

They permit the easy creation of maps, the updating of these maps as needed, easy changes in scale and map projection, and the production of a wide variety of other kinds of graphic displays of the mapped and related data.

AGIS's provide a variety of tools to enhance decision making; these include map overlaying, modeling, mathematical and statistical analyses, route and corridor selection and others.

They permit many kinds of complex situations to be more easily explained through the use of the displays and tools which are provided by an AGIS.

Because they reduce costs of dealing with data and costs of producing information products, AGIS's make it possible to examine alternatives seriously, and thus permit increasing the quality of decisions made as well as reducing the possibility of mistakes.

AGIS's allow decision makers to have timely information, at reduced costs, with fewer resources required, and with much greater confidence in the process by which the information is provided.

Trends Leading to Increased AGIS Use

Besides these advantages of AGIS use, there are a series of trends which are leading inevitably to greater use of AGIS's, with ever larger data bases being processed. These trends include:

Better and greater numbers of remote sensing devices

Much improved computer hardware

Emerging procedures for manipulating geographic and spatial data

Increased awareness of the potential usefulness of geographic information

Increasing world population

Increasing competition for natural resources

Reduction in the availability of natural resources

Reductions in global habitability

Conflicts in allocating resources

Recognition that problems don't stop at national boundaries

Increasing resources being directed toward the creation of very large geographic information systems

Increasing numbers of organizations, both public and private, which work in a multi-national or an international arena, and which demand information on these scales

World Problems to Which AGIS's Can Be Applied

There is a wide range of problems to which AGIS's could be applied, including many problems of world significance. These include, for example:

Loss of vegetal cover where it is caused by poor management of forestry, agriculture, grazing, soils or the like

Resource depletion caused by poor management of existing resources

Starvation and malnutrition caused by inadequate local production of food or by maladjusted distribution of food products

Failed development programs in the third world where these are due to poor planning or poor understanding of the local situation

Other problems of this type could be cited. To the extent that such problems can be dealt with through the more effective use of geographically or spatially referenced data, AGIS's can be useful in their solution.

Very Large and Global Data Bases

But coping with these problems by using AGIS's would require very large area or even global data bases.

Such data bases have been created and AGIS tools for creating more of them are available at the present time.

Problems

But there are problems which are making it more difficult to use AGIS's to help deal with these world situations. There are problems with the people and the process by which AGIS's and data bases are created, problems with the technology of the AGIS's and problems with the creation of very large and global data bases which are needed.

Aim of the Conference

While global data bases and other very large data bases can be created now, and would have most of the advantages already noted, the aim of this conference is to deal with the problems which nevertheless exist, trying to better define these problems and perhaps suggest approaches to their solution.

TOPICS DISCUSSED

It should be understood that the more than forty topics mentioned in the remainder of this report are nearly all related to one another; it is difficult to separate them from one another or to create categories which logically divide these topics into groups.

For this reason the discussion of a particular topic will often refer to ideas relevant to one or more of the other topics, and the topic headings are often unsatisfactory in defining the content of the discussion presented.

Also, while the topics have been divided into four categories for presentation in this report, other divisions might be equally satisfactory.

THEORY

Spatial Relations Theory

There is at present no coherent mathematical theory of spatial relations.

The world in which we live is a spatial world and to exist in it all of us master spatial relations on an intuitive basis. While these relationships are highly complex, we usually need not even think about them. We make use of the eye/brain combination to sort out the visual images we receive and recognize their various elements.

In dealing with spatial data in the form of maps, images and the like, we usually obtain the data with our eyes and then deal with the spatial aspects of the data on an intuitive basis rather than a logical or mathematical basis.

Unfortunately, when a computer must be instructed in how to perform such operations, intuition must be replaced by precise statements and by precise mathematical relationships.

At present we cannot supply this need.

The lack of a coherent theory of spatial relations hinders the use of automated geographic information systems at nearly every point. It is difficult to design efficient data bases, difficult to phrase queries of such data bases in an effective way, difficult to interconnect the various subsystems in ways which enhance overall system function, difficult to design data processing algorithms which are effective and efficient. As we begin work with very large spatial data bases or global data bases the inabilities and inefficiencies which result from this lack of theory are likely to grow geometrically.

While we can continue to make some improvements in the use of automated geographic information systems without such a coherent theory on which to base our progress, it will mean that the developments will rest on an inevitably shaky base and progress is likely to be much slower than it might be if we had a theory to direct our steps. It may be that some advances will simply

be impossible in the absence of a guiding theory.

It seems that the required theory is likely to involve ground breaking new mathematics and that the work involved will be difficult, perhaps requiring years of effort by many workers. Nevertheless, a theory of spatial relations would have important use not just in dealing with geographic data but with spatial data of all kinds, such as the data of physics, for example.

A proper first step, in the context of automated geographic information systems, would be to select a group of persons knowledgeable in the field and cognizant of the need for such a coherent theory, and have this group draft a statement of the problem. This report could then be used as the basis for gathering a group of suitable mathematicians and perhaps other theorists to examine the problem and devise approaches to it and suggest how such an attack could be mounted and supported; such a conference might take a week or so. From the recommendations of this theoreticians' analysis a concrete plan for supporting and directing research and other efforts might be designed.

It should be recognized that this effort may require many years and may branch into related areas as the work develops; quick payoffs ought not to be expected.

Recommendations:

A small group of knowledgeable persons should be selected to define the problem created by the lack of a theory of spatial relationships.

A group of mathematicians should be selected to meet and refine the problem statement and to identify what means are best adapted to its solution.

Research in the area should be funded and encouraged in such a way that significant progress might be made within about a ten year period.

Development and engineering implementation of the results of this research should also be promptly supported within the next twenty years.

APPLIED SCIENCE

Artificial Intelligence

Important, perhaps revolutionary developments will occur in artificial intelligence in the next twenty years and will probably have AGIS applications.

The research and development of artificial intelligence is presently receiving a great deal of attention both in the United States and abroad, perhaps particularly in Japan (the "Fifth Generation Computer" project); major resources are being committed to work in this area. From the level of effort devoted to the problem and from some of the precursor developments now being made it seems likely that important, perhaps even revolutionary developments will occur in artificial intelligence and related fields within the next twenty years or so.

Given the importance of mapping and automated geographic information systems (AGIS's) to science and technology, government, planning and a range of other activities, it is likely that artificial intelligence will be applied to AGIS technology.

But the application of this technology to AGIS's will require concerted and intelligently directed efforts by workers in both the two fields. This should be a continuing concern of the entire AGIS field and probably some formal efforts should be directed to ensuring that prompt use is made of artificial intelligence developments as they become available.

Particularly important will be systems giving computers "vision" (the ability to "see" and interpret maps), inductive reasoning (from maps and data),

logical analysis (for consistency checking and the like), and so on.

Probably the best way to apply artificial intelligence to the AGIS area would be to form interdisciplinary groups (perhaps at the research institutes suggested elsewhere in this report) of persons from computer science, artificial intelligence, cognitive science, ergonomics, engineering, remote sensing, geography, AGIS, the natural sciences and social sciences, and other suitable disciplines, so that the problems addressed can be seen in their broadest context and approached in a complete system context rather than in a piecemeal way.

Recommendations:

Developments in artificial intelligence need to be watched closely by the AGIS field and applied to AGIS technology as promptly as possible.

Interdisciplinary research institutes should be set up to insure that artificial intelligence is integrated into AGIS's within a broad interdisciplinary and total system development context.

Expert Systems

Expert systems which include AGIS capabilities are likely to attract new users to the AGIS field.

Expert systems, those in which the accumulated knowledge and experience of human experts in a field are incorporated into the algorithms of software programs in order to assist users of the software system in making choices and decisions in the field, are not much used with AGIS's at present. But combining expert systems with AGIS's seems a natural extension of this technology. Obvious applications in mineral exploration, oil exploration, forestry, agriculture and other related fields come to mind at once. Indeed the creation of such combined systems would be a natural outgrowth of

many of the recommendations offered in this report.

By providing AGIS users with the equivalent of an experienced system developer-programmer-analyst-applications specialist, standing at the user's elbow, expert systems could go a long way toward encouraging wider AGIS use.

Recommendations:

The development of expert systems helpful to AGIS users should be encouraged.

Artificial intelligence should be incorporated into such systems as it becomes practical.

Data Aggregation and Generalization

The need to aggregate and generalize data is a continuing technical problem in AGIS's and it is made more severe as data bases grow larger and approach global coverage.

The problem of data aggregation and generalization is a difficult one in handling any kind of data. Geographic information is also subject to the problem.

It is difficult to take data gathered at a large scale and readily aggregate it or generalize it for display or processing at a much smaller scale of mapping. Combining and generalizing data from different sources, perhaps gathered at different times, and created to different standards, also presents problems. Usually symbolisms must be changed, there is a need to somehow represent even minority contributions to the data, line forms must be generalized as the scale gets smaller, data of different reliabilities must be represented at some common accuracy, and so on.

Each of these problems, and many others, become worse as ever larger geographic areas are included in a data base.

A good deal of work needs to be done to solve these related problems.

Recommendations:

Continuing research and development attention needs to be paid to these problems, and practical pilot efforts with solutions need to be attempted.

Exploratory Data Analysis

As data bases become ever larger it is important to be able to use AGIS's to explore them efficiently.

Exploratory data analysis is designed to provide the means of identifying where, within a very large geographic or spatially referenced data base, there are areas which will be worth looking at more carefully. The process is designed to provide a means of "narrowing" a search, based on criteria identified by the user as interesting (such as data characteristics, combinations, relationships and the like). Exploratory data analysis has special utility when the problem under investigation is not well structured, or when one is still looking for some distinct pattern and has only limited ideas about what is significant; ideally exploratory data analysis can help recognize and bring out whatever patterns exist in the data.

Browse capabilities are the equivalent of "page turning" devices, allowing the user to see rapidly maps or other displays which the user has selected. Browse might be invoked after exploratory data analysis has identified areas where this page turning would be worthwhile.

A hierarchically organized data base would presumably be helpful to both these software capabilities.

Improved methods and algorithms for this kind of search need to be researched and developed.

Recommendations:

Methods and algorithms for exploratory data analysis and for data base browsing need to be further developed.

Data Base Queries

It is difficult to query very large data bases, but it is extremely important to be able to do so and do so efficiently and even quickly.

It is presently difficult and often time consuming to query very large data bases and the creation of global data bases will make this problem more severe. Moreover, it seems we do not know how to really improve this situation to any great extent.

Research is needed into how to structure data bases to facilitate data base queries, and into how to create queries to efficiently search existing data bases and new ones being designed. This area will probably require fundamental advances in the theory of spatial relations before important improvements are possible.

It is possible that the structure of data bases can facilitate dealing with queries. Certainly it seems likely that certain structures would facilitate some queries and make others more difficult. Questions of efficiency need to be answered by trials which compare the success and speed of various approaches; these data need to be publicized to help guide other researchers.

It may be that special "query languages" will be needed to facilitate the query process.

Many present systems for responding to user queries are very inefficient; while this may be tolerable with small data bases, very large or global data bases (containing a hundred-or thousand-fold more data) may make these inefficiencies intolerable. There may now be some kinds of questions which

we simply cannot ask of global data bases which possess considerable resolution or detail.

The solution to these problems is made more difficult by the fact that AGIS applications can be so diverse, that particular data bases will often be used to satisfy quite different user interests simultaneously, that one cannot predict what uses a data base will have in the future, that data sets are often added to data bases over time, that inconsistencies may be buried in data bases, and that aggregation and generalization problems have not yet been solved. Moreover, users will often pattern their queries based on intuition, hunches and the like, which may be very difficult to formulate in ways a computer can make use of; even for those seeking the same information, the method of attack may be seen quite differently.

It has been suggested that, since there are probably a limited suite of processes or operations that can be performed on a data base, one might begin the study of queries by breaking queries down into the fundamental operational "atoms" involved and then examining the possible combinations of these.

Recommendations:

Research and development in this area is especially important for the creation and use of very large or global data bases, and needs to be supported.

ENGINEERING AND TECHNOLOGY

Global Data Bases

A series of concerns must be addressed if successful global data bases are to be created for wide public use.

Global data bases have already been created by various government agencies and by some private firms, though not enough information is available about their experience to provide guidance for new efforts in this area.

It is clear, however, that global data bases can be created using present AGIS technology.

Given the present state of the art, though, these data bases will have higher than necessary costs, will not meet many users' needs, will lack flexibility, and may have fatal (but perhaps unanticipated) flaws. (It is obvious, for example, that one could create or conceive of a global data base with so much data that it would swamp the ability of present technology to cope with the detail.)

Nevertheless, such global data bases must be created and tested if progress in the technology is to be achieved.

To make significant improvement in global data base technology, most of the problems mentioned in this report will have to be attacked simultaneously. While some problems are more important than others, there are no easy targets which, if solved, will sweep away all difficulties. Instead, a push on a broad front will be required.

Users

There are some 3,000 or so organizations, public and private, which do business at the multi-national or international level. A global data base of natural and cultural resource information, mapped at a scale of 1:250,000 using Landsat imagery, could be paid for if only a tenth of these organizations each contributed less than a million dollars each.

Whether such a "global information utility" could win the support of hundreds of such organizations is more problematical than the technology

needed to create the system. But since such data bases are more likely to receive use at the national or the multi-national more than on a global basis, overlapping and cooperative use may not be so critical a problem.

Data Base

Initially it may be more important to get agreements on data formats, structures, etc. than it is to create the data base. If agreements can be reached, then the data will be available in a useful form later on.

Failing this, it would be best to adopt the best standard that can be devised and then create the data base in spite of a lack of cooperation, perhaps by using remotely sensed data as surrogate for what would otherwise be obtained by ground based methods. Such an approach would have the virtue of producing a real data resource which might come to be used even by countries initially unwilling to agree to any standards.

Data consistency and reliability will be a severe problem in any global data base if the data must be gotten from a long series of national organizations which differ in their goals, methods, etc. Given this problem it may be better for some classes of data to simply create "pointers" to data resources rather than bringing them into the data base. In many cases just knowing that data exist will be of extreme importance; knowing this for a significant part of the world's data resources would be a great step forward in dealing with world problems. If automation of these data became important, it could be done at any later time.

It is possible that all the data in a global data base might be organized according to a single comprehensive system or "schema". Desirable features of such a schema would be that it cover the entire globe, be consistently referenced and logically consistent throughout, work well at a variety of

mapping scales and data resolutions, be indefinitely expandable as new data are gathered, be readily subdividable into parts, be suitable for use by the computers processing the data base, be consistent with a general theory of spatial relations, and in all other ways conform to the best available theory and technology of the time when it is instituted.

It may be that no single schema can be devised to meet these criteria, so that multiple schema (perhaps one for the oceans and another for the land) would have to be used; hopefully these multiple schema would be able to interact with one another.

Other situations are conceivable, including the worst case in which many schema are devised, none of which can interact with one another.

It seems that any global data base should be hierarchically constructed and that the hierarchy permit aggregation of data upward to smaller mapping scales. This aggregation will be critical for global decision making applications.

Many of the features of a global data base's organization may require new technology and new ways of thinking about data bases.

Data Needs

At present no one knows what the minimal data requirements are for decision making at the international level, nor probably at the national level. What kinds of data, at what resolution, of what reliability, are required for planning on an international basis is not clear. Research and testing in this area is very important. It is probable that the minimal needs will vary from application to application.

Also needed are analyses of the decision making processes used by the organizations which might be users of such global data bases; these analyses are needed to further determine what kinds of data, what resolutions,

availabilities, reliabilities, costs, etc. are appropriate for a global data base.

Data Collection and Data Entry

Assuming that the needed data had been identified, the development of a global data base might be phased. The most available needed data (probably Landsat imagery or its equivalent) could be entered first, especially where it could provide for an otherwise missing base mapping set. Mapping could begin in those areas which were of highest interest and proceed to other areas on a demand basis or as sponsors are found for mapping those areas. The most valuable (used) or perhaps the most conservative (long lasting) data (geology, soils and the like) might be added first. The most difficult to acquire, the most costly, the least used, etc.-- provided it was not critically needed-- could be gathered and included later, perhaps on a patchwork basis.

Recommendations:

A variety of problems dealing with creating a global data base will need to be addressed simultaneously if progress is to be made.

Pilot studies of global data bases need to be undertaken.

Improved Data Automation

Data automation is probably the biggest bottleneck in AGIS function at present and represents the greatest single cost in most projects, especially where the data base is very large.

The process of data automation or computerization is a technical one, subject to many kinds of errors and inaccuracies. It must be performed to

very high standards or the usefulness of the entire AGIS may be vitiated.

The process involves not just the automation of points, lines and polygons (vector data), or gridded data (raster data), or of other kinds of data (imagery, statistics, attributes, and so on); the process also involves the preparation of that data for automation, data integration, data reformatting, and so on.

Improvements in these processes would go a long way toward making the use of AGIS's much more attractive.

While many of the problems in automation are related to the data which are to be used (inconsistencies, errors, poor source materials, outdated sources, etc.), many problems also have to do with the technology used in automation (hand coding, key punching, digitizing, line following, scanning, etc.).

While new technology is developing in these areas, the pace ought to be speeded up if at all possible because the problems hamper the adoption and use of AGIS's perhaps more than any others on the technical side.

Unfortunately the means of speeding automation of data are not clear. Additional research and development in this area is needed and should encompass both hardware and software as well as production flows. As in other topics covered in this report, progress needs to be made in a number of other areas if progress is to be made in data automation. The use of artificial intelligence might be very important in data automation, but awaits its own development. "Feature recognition" would be extremely useful, but is not yet well developed. Electronic scanners would be very useful, but they presently have drawbacks for many automation applications. Error correction methods are still quite primitive. This list could easily be added to.

When improved techniques are developed, tests, benchmarks, ergonomic and

economic studies need to be used to compare present methods with the improved ones to be sure that the innovations represent progress. Such tests and studies may also provide direction for improvement.

While it is recognized that this is an area in which competition among vendors is likely to drive improved technology, the proprietary nature of these improvements may make rapid progress across the field more difficult.

This is an area in which documentation of successes is especially important, since increased efficiency will depend at least in part on improved work flows and management. Good data on present costs and throughput is very difficult to obtain, so documentation of even present methods is important as a baseline to work from.

Recommendations:

Research and development in this area should have the highest priority.

Research and development in a number of related areas may need to be done before progress in automation can be significant; these areas probably include feature recognition, cognitive science, artificial intelligence and others.

Documentation of present methods, costs and throughputs needs to be obtained to provide baseline data against which potential improvements can be measured.

Data Editing

Data editing functions of AGIS's need to be greatly improved, especially as data volumes increase.

Editing of data for inclusion in AGIS data bases is an extremely laborious process which has so far only been partially automated.

What is required is the equivalent, in geographic information terms, of text editing programs which automatically correct spelling and grammar.

This is an area in which artificial intelligence may be very helpful. Searching out logical inconsistencies (trees in the middle of lakes, where there is no island; etc.) in entered data is but one possibility. Dozens of kinds of automated editing steps are already included in some systems, but manual editing (often through visual comparisons) is still required; this needs to be automated.

Along with digitizing or automation of data, editing is one of the critical bottlenecks in the entire AGIS work flow.

Recommendations:

Continuing research and development of automated editing is needed.

The use of artificial intelligence in support of such editing should be examined closely.

Data Updating

Improved methods for updating the data in data bases are needed.

One of the causes of the failure of AGIS's to meet users needs is that with time the data in the data base become outdated and obsolete. When users discover this they lose confidence in the data base and the system of which it is a part. Short of this there are also considerable problems associated with updating any data base.

While there are means available for updating, better means are needed and as very large or global data bases are created this problem will grow proportionally severe.

As the diversity of data included in a data base increases there are also increases in the problems; different data need different kinds of

updating, need to be updated at different intervals, must be updated by reference to quite different source materials, and so on. All these matters must be taken into account in any designs for data updating.

Recommendations:

Continuing development of updating methods is of great importance to the integrity of data bases and to the maintenance of user confidence in AGIS's.

Economics of AGIS Use

More agencies would use AGIS technology if they had better information about the cost/benefit ratios and the economics of AGIS applications.

There are many potential users of AGIS technology who would employ it where they now use manual techniques, if they had more definite information about the costs involved and they knew whether AGIS's could be cost effective in comparison with their present methods.

Because of the lack of this kind of information many valuable applications of this technology do not take place and much money and time is being wasted, often in areas critical to the future of individual nations and the world as a whole.

It is important that careful, independent and objective studies be made of the economics of the use of AGIS's in various applications, and that the results of these studies be more widely communicated than they are at present.

These analyses should go down to the level of individual AGIS functions so that the cost for digitizing polygons, for overlaying maps, for plotting lines, and so on are fairly well specified, and specified by particular applications as well.

The speed of individual operations should also be known (throughput analysis).

While it may be impossible to estimate the costs of new applications from such analyses, since completely new information flows may be necessary for each new application, yet, over time and with increased volumes of work in each application area, such estimates may become more feasible.

Recommendations:

Economic and throughput analyses of AGIS functions are important to the development of the field, and the performance of such analyses and the publication of their results needs to be encouraged.

Benchmarking

Benchmark tests would probably be useful in measuring the performance of a wider variety of AGIS functions, and should probably be more widely used in selecting systems.

Benchmarks are standard tests given to competing automated systems to determine which performs best; these tests are used in both the computer field and in the AGIS field. To provide some objective guidance about system performance, they ought to be used more widely.

It is admitted that there are flaws in the benchmarking process, and that the benchmark tests must be carefully designed if they are to measure those factors which are of real interest to the users once the system is purchased. Benchmarks are thus quite specific, and applying their results to wider contexts is inappropriate.

Nevertheless, more effort needs to be directed to the design of good benchmarks and those knowledgeable in this field should be urged to share

their special knowledge more widely.

Some publication of the results of benchmarks, accompanied by appropriate cautionary statements, might also be useful. A professional society might look in to this to see what could be done to effect this wider distribution of information about system capabilities.

Recommendations:

Benchmarking should probably be used more often in selecting AGIS's.

Persons expert in the design and conduct of benchmark tests should be urged to share this knowledge.

Some publication of benchmark results would be useful to potential system users, if accompanied with appropriate cautionary remarks.

Case Studies

Use of AGIS's is inhibited in many cases because of a lack of reliable information about what such use entails in terms of time, cost, personnel and other resources, and a lack of information about the course of events which application of AGIS's requires.

Especially during the early period of a new technology's development and application-- the period before practice is described fully in the textbooks and in the training of those working in the field-- there is a great need for those working with the technology, and those considering its use, to be aware of what has been tried, how well it has worked, and what seems to be successful.

Scientific papers, papers at conferences, reports prepared by vendors of systems or by systems users, and many similar documents prepared by those closely involved in applications, are not always the best means of learning about the field and what its successes and failures are. Often they gloss over the failures, misdirections and dead ends which others need to know

about. Moreover, reports written by those too close to the system have inevitable biases built into them.

Case studies of the entire systems cycle for particular AGIS's and AGIS applications are a way of providing the needed kinds of information to a wide audience. When carefully conducted by third parties, perhaps especially by outside "watchdog" agencies (accounting offices and the like), or by consultants not directly involved in the process, or researchers, these case studies may be especially valuable and objective.

Were the entire process supported by professional organizations or societies, with a recognized standard format to ensure that all needed questions were raised and to provide commonality in an extended series of such case study reports, the process would be further enhanced.

Case studies of AGIS's ought to take into account such topics as the setting of the project, the impetus leading to it, the original system concept, the way in which the project was to be funded, how consultants (if any) were selected, how the system was designed, how vendors were selected, the costs for hardware and software, the user needs study, the time table for implementation, the nature and extent of training, any pilot studies undertaken, the actual timetable of the project, the problems encountered along the way, the initial uses made of the system, the longer term uses, the economics of the applications, the results in terms of the original objectives, the effects on decision making, the reactions of users and others to the use of the system, a bibliography of publications about the project, and perhaps other topics.

Recommendations:

Documentation of uses of AGIS's in the form of case studies should be encouraged.

If at all possible, third parties should carry out these case studies, in order to ensure greater objectivity in the studies.

Steps should be taken to ensure the wide distribution and availability of these case studies.

Funding (estimated at about 3% of total project cost) should probably be included in AGIS project budgets to ensure that documentation of the projects is performed so that case studies can be carried out.

Documentation of Applications

It is important that potential users be aware of what it takes to apply AGIS to their particular problems, what models exist which may apply to their needs, and what successful applications like theirs have already been done.

It is important that information about various applications of AGIS's be more widely distributed. Potential users must know what AGIS's are good for, and not so good for, if they are to make sound decisions about acquiring AGIS's and then using them effectively after acquisition.

Successful applications and applications packages need to be identified, documented, collected in various ways and then published and otherwise communicated to potential users. Some sort of "applications notes" might be parts of a professional journal, or distributed as occasional papers by a professional society, a clearinghouse operation, or the like. Independent observation or editing might be especially valuable in such notes, to ensure their credibility. The publication of these success stories is probably essential to the growth of the field at the rates needed.

A second element which needs to be publicized is the existence of computer models which, when coupled with AGIS's, are designed to help manage natural or other resources. Specialized models of this kind, in forestry, agriculture, geological exploration, biological research, hydrology, river

basin planning, environmental monitoring, pollution abatement, transportation planning, urban and regional planning, etc. are obvious examples of what are needed.

Finally, it is important that decision makers have a fairly clear idea of the functional requirements of a wide range of specific applications which they might want to consider. They need to know what data would be required (type, resolution, scale of mapping, reliability, etc.), what kinds of work flows would be needed, system characteristics, staffing, and so on. While these cannot be specifically given for ever application situation, more could be specified than is presented in the literature now.

Recommendations:

Efforts should be increased to obtain prompt publication and dissemination of information about successful applications, perhaps through the auspices of a professional society, clearinghouse operation, or like mechanism.

Algorithmic Analysis

Sustained and organized study of existing software needs to be undertaken and supported.

In order to identify effective existing algorithms and software systems, to identify areas for additional research and development, to relate algorithms to theory, to classify existing algorithms, to identify the theoretical classes of algorithms, to evaluate the ways in which algorithms are combined in functioning AGIS's, etc., and to make the results of all these analyses more widely available, serious studies of algorithms must be undertaken on a broad base.

These studies will be inhibited by the proprietary nature of the

software used in many AGIS's, but it may be that flow charts will be easier to obtain than source code. Much could be done with software already in the public domain and even with obsolete systems.

Recommendations:

Suppliers of AGIS's should be urged to cooperate with such efforts; it may be that joint research efforts involving many system vendors is possible in this limited aspect of AGIS software.

Software

Computer software development is a continuing problem in the AGIS field and limits capabilities far more than does hardware.

In the AGIS field as in most areas of computer application, software is now perceived as a much greater problem than hardware.

More firms, organizations and universities need to get into the effort to create such software and the incentives for software creation need to be increased by various means; more money needs to be put into software creation efforts and well trained mathematicians and programmers need to be attracted to the field.

But there are problems intrinsic to all kinds of computer software development. Much of the existing software is proprietary and source code is not available for examination, so development often occurs in a vacuum, with little knowledge of what else is going on in the field. For this reason universities and research centers cannot freely study existing software and develop improvements; this must be left to businesses in the field. It is very difficult to compare the efficiencies and features of various softwares under these circumstances. Software is expensive so that it is

costly to include it in the education of students. Software vendors are reluctant to donate software to educational institutions lest the source code be distributed without appropriate fees being paid them, or find its way into the hands of their competitors.

While this situation produces inefficiencies in software development, only structural changes in the industry would alter the situation; these are unlikely to occur.

The only other obvious alternative may be the creation of an industry-wide agreement to conduct joint research and development and then share the results. This seems an unlikely approach.

Recommendations:

Additional resources need to be devoted to software creation and the incentives for software creation need to be increased.

If better systems for creating good software can be devised, they deserve support and encouragement.

System Linkages

Better linkages are needed between various kinds of data in a single data base, between different components of single systems, and between different systems; data sharing agreements need continuing encouragement.

There are several different kinds of linkages between systems which need continuing attention in the AGIS field.

First, it is important that better linkages be created between data of various forms. Image data, cartographic referencing, statistics, text, bibliographies, diagrams, etc. need to be linked together within an AGIS so that they can be used together. In preparing reports, reviewing all

the relevant information for planning or decision making, preparing display materials, etc. intimate linking of all forms of data would be extremely valuable. Effective links would encourage both wider use of AGIS's and broader application diversity in those uses.

Additional work also needs to be done on linking complete systems together: linkages between systems created by different vendors; spatially separated systems; systems designed for different purposes; systems using different programming languages and different data base structures.

It is also of continuing importance to press for wider sharing of data, especially that already automated. As projects are initiated it is important that agreements be reached about sharing data with other organizations, other projects, archiving the data, making it available to central data bases, and so on.

These are all areas where standards may be helpful and discussions about such standards need to be ongoing.

Recommendations:

Systems vendors, users, government and professional organizations need to continue to work toward agreements and technological solutions to making more effective linkages possible.

Computer Hardware

The needs of AGIS's for hardware will probably be met chiefly due to marketplace pressures now leading to rapid advancement in hardware capabilities and rapid declines in cost; nevertheless, some improved hardware capabilities would be valuable to the AGIS field.

While hardware capabilities seem likely to be provided by the market

forces in the computer hardware field as a whole, there are differing opinions about whether the price of these hardware devices is favorable for development in the AGIS field.

On the one hand it is argued that the capabilities of the hardware are so great that at the present time hardware is greatly under priced; the cost/benefit ratio is very favorable, either in comparison with earlier hardware or in comparison with manual systems for doing the same work.

On the other hand it is argued that prices must come down manyfold before systems will be inexpensive enough to be widely used-- or at least as widely used as would be profitable and beneficial for the wide variety of users who might employ AGIS's.

Regardless of these arguments, there are some hardware devices which are not available and which need to be developed for AGIS use in the near term.

Optical scanners, capable (with artificial intelligence) of gathering all kinds of mapped data directly, might go a long way toward breaking the bottleneck in data automation, presently probably the biggest bottleneck in AGIS function.

As masses of data in global data bases have to be stored and processed, the speed of computers and their storage capacity are both likely to be severely taxed.

It has also been suggested that parallel processing computers may be well suited to some of the algorithms used in AGIS's, and may solve some of the problems with processing speed.

There is a continuing problem in making data bases and software portable from one vendor's hardware to another, and anything done to ease this problem would be advantageous to AGIS's users.

Finally, it must be admitted that the perceived capabilities of present day and foreseeable hardware probably are determining our conception of what AGIS's can do.

Recommendations:

In special cases, where AGIS's are the chief user of some hardware devices, special efforts may be needed to obtain the capabilities required, since market forces may not otherwise lead to their being created.

AGIS system designers need to rapidly integrate new hardware capabilities into their systems if the needs of very large or global data bases are to be met.

Ergonomics

Although the theory underlying ergonomics is not mature, ergonomic studies are important if AGIS's are to be made more useful and efficient.

While the theory underlying ergonomics is probably not mature, and while a good deal of the work in ergonomics in the computer field generally and in AGIS applications in particular is probably suspect in its results, nevertheless, ergonomics is important to the efficiency, usefulness and user friendliness of AGIS's.

Probably more work needs to be done on the theory and practice of ergonomics itself. In the computer field the interest in ergonomics seems to be more cosmetic than serious. Some serious research efforts are probably required to remedy this.

As soon as they can be soundly based, ergonomic studies are needed of the full range of AGIS functions and AGIS applications. Especially important are the display technologies, data entry, and human interactions with data of all kinds. Micro computers need to be compared with minicomputers and

with mainframes.

While ergonomically effective solutions to various AGIS problems may exist at present, they need to be engineered into real systems which receive wide distribution.

Recommendations:

Ergonomics must be put on a sound basis and then applied rigorously to AGIS technology.

When ergonomically sound systems are designed, they need to be promptly implemented in production models.

AGIS Standards

The use of standards for AGIS's involves important choices and both benefits and problems.

Every independent, non-standard initiative toward the creation of very large geographic data bases, especially global data bases, may be a source of problems later when it is desired to make use of two or more sources of data and the data are not compatible. Thus there is a considerable incentive for adopting standards and a penalty for not doing so.

But premature adoption of standards may result in gathering and storing large amounts of data in ineffective, expensive, or theoretically unsound ways. So there are risks in adopting standards for data.

There are a whole host of other standards (for data interchange, for software, for hardware, for output formats, for scales of mapping, and so on) which usually offer parallel benefits and risks.

Adopting standards in the AGIS field now is probably premature. The diversity of functions, applications, project types, and so on seems to preclude extensive standardization; too many compromises would be required.

It may be that over time some standards will naturally emerge, perhaps due to competition in the marketplace, or market share of the vendors, or clear technical superiority.

Permissive standards, possibly a range of them from less to more sophisticated, might be useful. Users of AGIS could voluntarily adopt a standard and publicize the fact, thus allowing others to know the technical features of a particular AGIS and the degree to which their own system would be compatible with it. A hierarchy of standards might permit partial compatibility between systems which are dissimilar.

This issue of standards is a complex and subtle one and requires continuing attention.

Recommendations:

Continuing attention to the question of standards is appropriate, especially as global data bases are created.

This is another matter in which cooperative efforts and professional organizations might play a useful role.

Geographic Referencing Systems

Geographic referencing systems may have to be reexamined in light of AGIS use and the creation of global data bases.

It may be that existing means of referencing geographic data will not prove well suited to global data bases which are maintained on AGIS's. As yet undefined substitutes may be more efficient, easier to work with, and more unobtrusive to the user. Spatial referencing is a more general problem than is geographic referencing and it may be that developments in a theory of spatial relations will suggest new referencing systems. A general schema for a global data base may also lead to the definition of

an appropriate geographic referencing system for the data base.

These possibilities need to be considered; no hasty adoption of a referencing system is justified at present.

Recommendations:

Developments in the theory of spatial relations, in AGIS's, and in schema for a global data base may all influence the choice of a referencing system for a global data base, and all should be considered as this choice is made.

User Friendliness

AGIS's need to be user friendly.

AGIS's need to be made more user friendly, but it is clear that this is neither a simple concept nor one that is easy to implement.

User friendliness implies human factors or ergonomic design, an area in which a great deal needs to be done.

User friendliness implies that the system is suited to the user's needs, but an engineer, a sociologist, an economist, a land use planner, an elected official, or any of dozens of other users with specialized interests will each have particular points of view on what is friendly and what their needs are.

Moreover, as a user becomes more skilled, less in the way of "friendliness" will be needed-- or wanted; so systems will have to respond with friendliness at various levels.

These kinds of problems will be more important as one creates systems which will be used by more and more people, of different countries, different languages, different education and familiarity with technology, etc.

Recommendations:

Serious (as opposed to cosmetic) attempts at creating user friendly AGIS's need to be continued, using the best guidance available from a wide range of fields, such as ergonomics, cognitive science, etc.

Need for Improved Efficiencies

There is a need for improved efficiencies in nearly every aspect of AGIS function.

Although they are powerful systems, AGIS's, which are really still in their infancy, are often inefficient in their functions.

The automation of data is too slow and represents probably the greatest bottleneck in AGIS function at the present time. Algorithms for most functions are probably much slower than they might be, although improvement in some cases will have to await a coherent theory of spatial relations. Costs of AGIS's and of operation are too high.

While these inefficiencies may be tolerated by many users because the systems still have a good cost/benefit ratio, improvements can and should be made wherever possible.

Recommendations:

Efforts in software development, algorithmic analysis, data base structure design, ergonomics, engineering economics and a whole range of other areas are needed in order to achieve improved efficiencies in AGIS function.

INSTITUTIONS

NAS/NRC Definitive Study

A neutral, competent and respected body needs to examine the field of automated spatial and geographic information systems and prepare an evaluation of the problems and promise associated with it.

If government support and funding for research and development in the AGIS field is to be obtained in any consistent way over the long term, a neutral, competent and respected body of experts will have to prepare a case statement for such long term support.

A respected mechanism for preparing such a study and making recommendations which will be listened to is the convening of a National Academy of Sciences/ National Research Council panel to prepare a "definitive study" of the problem.

To obtain this end a number of steps will be required.

One or more federal agencies will have to be interested in the objectives of the study.

One of these agencies will have to take the lead agency role.

The interested agencies will have to contribute money to pay the NAS/NRC for conducting the study.

Recommendations:

A NAS/NRC "definitive study" of the field should be made.

Federal agencies should be approached and interested in such a study and from among them a lead agency should be found.

Funding for the study needs to be solicited from a number of federal agencies.

Archival Storage of Data

A problem of pressing importance is the need for archival storage of imagery and data already gathered.

The face of the earth is changing rapidly at present and may change even faster in the years ahead. Many studies, especially those seeking to determine the consequences of change, will have to be done over a long period of time and will require baseline data as well as sampling over time. Many such studies will, of necessity, be retrospective.

For these and other reasons it is important to preserve imagery and data already obtained, and provide the means for preserving newly acquired materials.

An archiving facility or facilities is called for. While some archiving of imagery and data is being done, more is required and the entire process needs to be rationalized and organized.

A central archive or scattered archives for global data resources are both possible. Cooperation, international agreements, or purchase of the resources are all ways of obtaining the data. National or international support, or fee-for-services are possible financing methods. Given the importance of U.S. federal agencies in the creation of such data, legislation or policy may be required to ensure needed cooperation. This is an area in which government might profitably cooperate with industry and the universities; professional organizations might help arrange such cooperation.

Until a rationalized process is devised, it is vital that the present scattered efforts at archiving be supported and encouraged. Data are being lost irretrievably, every day.

Organized and continuing efforts need to be made to evaluate various storage media for their suitability as archiving media. At present laser written disks seem attractive, but this technology is advancing very rapidly.

The design of the archiving system must also consider the preparation of the data for storage, the documentation of the data, the facilities for re-acquiring the data from storage, the standards for what data are accepted for archiving (including quality, reliability, and so on), methods of financing, security, and so on.

Associated with such facilities must also be a comprehensive index and an automated search capability, probably accessible from remote terminals. Associated AGIS facilities may also be useful for providing output and processing in various ways.

The case for the importance of such facilities, suitable staffing, and publicity to insure that those with the data will submit it for inclusion, must also be pursued.

But above all, strong efforts must be made to preserve the data resources which now exist, since they are a presently wasting resource which cannot be replaced.

Recommendations:

Immediate intense effort needs to be made to secure the archiving of the irreplaceable data and imagery we have already gathered.

Longer range efforts need to be made to provide for archiving facilities.

Everyone involved in gathering or using these data needs to be supportive and cooperative with this effort.

Improved Communication

Communication between persons within the AGIS field and between the field and persons and organizations outside the field need to be greatly improved.

There are a whole range of communications which are important to both the AGIS field, the people working in it and those who may make use of the technology or its products.

In those areas where automated geographic information system technology provides satisfactory methods for solving problems which are known to exist, it is important that these methods be more widely known about so they can be practiced. Communication of these capabilities is needed.

Researchers and practitioners in the field must communicate with one another more often and more effectively if the field is to grow rapidly.

The results of benchmark tests, case studies of AGIS projects, applications of AGIS technology, and a whole range of other documented results must be more effectively communicated to a wider audience.

People and organizations in the field must communicate more effectively with funding agencies, people outside the field who might effectively use AGIS's and the public.

The emerging nations of the world need to know more about AGIS's since this technology could have an important impact on their ability to govern and plan more effectively.

Users of this technology need to communicate with those who are creating it and with those who are educating future practitioners in the field.

Leaders within the field, from government, industry and the universities, need to discuss areas in which they may usefully cooperate.

Decision makers need to learn more about how to select AGIS's, implement them successfully and then use them in appropriate and cost effective ways.

Many other portions of this report make this need for communication apparent, and offer specific suggestions for improving communications in various ways.

Recommendations:

A wide variety of communications means needs to be adopted and concerted efforts need to be made to make communication more effective and frequent, within the field and with those outside it.

Technology Transfer and Diffusion

The transfer and diffusion of AGIS technology to new users, especially in the developing world, is important.

AGIS technology has a wide variety of applications (see OPENING DISCUSSIONS) which make its application of considerable benefit to many kinds of users, perhaps especially those in the developing world.

While private businesses in the AGIS field naturally find it in their interests to promote the transfer and diffusion of this technology to new users, and while various universities and other organizations promote this transfer through research, education and training, more still needs to be done in concerted ways to promote the wider spread use of AGIS's and their associated data.

It has been recognized that there are a natural series of stages in the overall process of technology diffusion. These range from simple knowledge of an innovation to complete adoption and use of it. Because of the complexity of AGIS technology (its relationship with computers, other hardware, software, decision making, remote sensing, geography and the sciences) even knowledge of the technology is not easy to communicate. Coupled with all the problems of cost, changes in attitudes, rapidly obsolescent hardware and software, etc., the problems of transfer of AGIS technology are formidable.

This is an area in which more needs to be known about what methods of transfer have worked in the past, in what situations they have worked, and

about how this knowledge can be successfully applied in new transfer situations.

Recommendations:

Continuing attention needs to be paid to this problem and successful methods for promoting transfer and diffusion need to be found and more widely used.

Seeing AGIS as a Discipline

The study and use of automated geographic information systems and of spatial data systems should be considered as a discipline or field of study rather than just the application of a technology.

Some view AGIS technology merely as a tool, but it may be fairer to compare it, not with a microscope or even with a computer or satellite, but with statistics or operations research. The use of AGIS's provides a way of viewing reality and studying reality. To practice in this field requires considerable study, a broad background in a number of scientific and technical fields, an appreciation of a good many subtleties about AGIS use, and probably a fair amount of experience. There are parallels between AGIS work and the work done by architects and engineers: both involve design efforts; projects costing hundreds of thousands or millions of dollars; the practice of skills and the use of knowledge acquired over some period of time; knowledge based on both practical experience and considerable academic study; and a wide range of ethical and professional concerns to be dealt with. The acquisition of the needed skills and knowledge goes considerably beyond what is required to master instruments or techniques. These and other considerations suggest that the study and use of AGIS's is really a discipline, not just the application of a technology.

For persons who employ the discipline by selling their services, the AGIS field may be something akin to a profession, at least insofar as practice may require professional ethics and concern for the common good.

It is possible that the development of this entire AGIS field will move more rapidly forward if the field is recognized as a discipline or a sub-discipline with all that may imply.

These disciplinary or professional aspects of the field are potentially important to the field if they lead to such things as increased recognition for workers in the field, increased funding, increased research, better communication and concerted attacks on outstanding problems.

Recommendations:

Continuing efforts are needed to foster this perception and support it with concrete actions.

A Society for Spatial Information Systems

To promote various disciplinary and professional goals and activities, a professional society dealing with the AGIS field and related areas is needed.

As a part of the effort to create a supportive environment for development in the AGIS field it may be useful to found a professional society to encourage mutual recognition of those workers in the field, to provide a means of communication among those interested in or working in the field, to perhaps create a professional journal devoted to the field, to hold periodic meetings for professional exchanges, to help organize concerted efforts to attack the problems in the field and for other professional purposes.

It would seem wise to have individual members, business or corporate members and perhaps other classes of members in order to achieve all the various purposes

such a society might effectively serve.

Recommendations:

Steps should be taken to found a professional society dealing with spatial information.

1984 Meeting in Zurich, Switzerland

In order to promote development in the AGIS field and closely related fields an early international meeting should be held.

In order to focus attention on the field, review the present state of the field, discuss the formation of a professional society, encourage exchange between those working with AGIS's, and for related reasons, an international meeting on AGIS's and related topics should be held soon.

An excellent opportunity for such a meeting is presented by the arrangements already made for a meeting in Zurich, Switzerland in 1984, under the auspices of the IGU (International Geographical Union). A hotel has been secured, ample meeting space is available, a period of about a week is available for such a meeting, and many of those attending the IGU sponsored meeting would also be interested in spatial data handling. Support for this additional meeting can probably also be obtained through co-sponsorships from various professional societies.

Recommendations:

An international meeting on spatial data handling and related matters should be held in Zurich, Switzerland in 1984.

Persons active in AGIS work and related fields should be encouraged to attend and supported financially where possible.

Supportive Environment

If the AGIS field is develop rapidly a more supportive environment will be needed for those working in the field.

While it is possible for technological development to occur even against considerable odds and despite obstacles, the rapid development of technology can be fostered and supported. The AGIS field needs such support at the present time if the benefits of the technology are to become rapidly available the many potential users.

A supportive environment involves many things. More research needs to be done in the field and it needs better funding. More people need to be educated and trained for work in the field and the quality of that education and training needs to be improved. More money needs to be available to help users-- especially in the third world-- obtain the benefits of this technology. The field must be perceived as a discipline and probably needs to adopt some kinds of professional standards for at least some of its activities. Better communication is required between all those in and related to the field. These and other matters are but facets of such a supportive environment.

Support must probably also involve a few important individuals. To create such a supportive environment may require attracting to the field a number of brilliant and charismatic figures who can inspire the larger group of researchers and workers required. A few key individuals in government will also have to be persuaded of the importance of this field and will have to land

their continuing support. These individuals will have to keep in touch with one another so that synergism can be achieved.

To achieve this supportive environment a concerted plan may be required, and efforts over many years will certainly be needed.

Recommendations:

This support will need to be created, planned for and fostered on a continuing basis, and the efforts will have to be well led.

Institutions Needed

A variety of specific institutions will be needed if the AGIS field is to grow and meet the demands which will be placed on it.

In addition to a generally supportive environment, a variety of specific institutions will be needed to support the growth of AGIS technology and its dissemination to potential users.

In colleges and universities training persons in such fields as remote sensing, geography, computer science and the natural and social sciences, programs for education and training in automated geographic information and spatial data systems need to be created, staffed and supported.

Centers for research into AGIS problems should probably be set up at a few major university centers where a significant group of researchers in this field already reside.

A professional society dealing with this general subject area probably needs to be created and sustained.

Additional well qualified consultants are needed in the field, and lacking

them other measures must be devised to meet the need for sound consulting advice.

Additional business and entrepreneurial activities will probably be needed in the field to supply the growing demand for AGIS's and the services associated with them.

To create and maintain these and other needed institutions will require planning and concerted effort as well as resources.

Recommendations:

Those in the field will have to plan for, create and support such institutions on a continuing basis.

AGIS Education

Improved education and training for working with AGIS's is needed, and more students need to be prepared for the field.

To meet the need for growth in the field more persons will need to be educated and trained in AGIS technology and its application.

To provide such education and training a number of steps must be taken.

Additional graduate programs, at both the Ph.D. and Master's levels, will be needed. Both the government and private industry should probably be involved in supporting such programs since both have much to gain from their success. Centers of excellence are likely places for the founding of such programs.

Both graduate and undergraduate curricula now existing will probably need some modification if persons are to be able to move into the AGIS field. Model curricula might be devised and publicized to help meet this need.

Retraining of persons already in the field, refresher courses and similar efforts are also important. They must meet criteria for attractiveness, convenience and other features rather different than those associated with undergraduate and graduate education.

Another group of persons who need to be educated are the decision makers and managers who will make use of the products of the technology but who may not interact directly with AGIS's.

Each of these groups may need to be handled somewhat differently, educated in different contexts, using different approaches and materials, and taught by different kinds of instructors.

A particular problem in creating the institutions which will provide this education and training is the cost of the equipment required for working with AGIS's, chiefly the computer and peripheral hardware needed. While the systems used need not be completely up-to-date or as powerful as those used in government or industry, the costs can still be considerable. Government and industry might work with the universities to help make the needed system components more readily available to educational institutions. Obsolete hardware might be provided through clearinghouse arrangements.

The increasing power of microcomputers may also have an impact on both the equipment problem and on education and training more generally. Since it is now possible to obtain considerable parts of an AGIS software suite for only a few thousand dollars-- software that will run on a microcomputer-- a working version of a rather complete AGIS is now within reach of many institutions.

Obsolete software might also be given freely to educational institutions as newer software takes its place in commercial applications. Surrogates for software might also be provided in the form of written documentation (where source code is proprietary); such documentation would permit students to study

the algorithms, structure and other features of the software without compromising the proprietary rights of the supplier.

Cooperation among all those interested in the field will be necessary if these and other solutions to the educational problem are to be implemented successfully.

Recommendations:

Additional graduate programs, at both the Ph.D. and M.S. levels, are needed.

Curricula need improvement and model curricula should be devised and publicized.

A variety of other educational and training opportunities are needed for refreshing and retraining those in the field, and for training potential users of the technology.

Equipment and software need to be provided for such programs; government and industry might cooperate to help meet these needs.

Research Institutions

Not enough research is presently going on in the AGIS field.

The lack of research in the AGIS field and more generally in the study of spatial data handling is due to a host of reasons:

Lack of professors qualified to direct the research in this area

Lack of funding for research in this area

Lack of needed equipment, chiefly computer hardware

Lack of a critical mass of persons in the field and also resident in a single institution

Lack of identification of AGIS's with a distinct discipline

Lack of recognition by other faculty in related disciplines that GIS's are worth studying and working with

Lack of recognition by peers for work done in the AGIS field

Lack of students who know the field exists

Lack of students who want to pursue advanced degrees when they can be well paid immediately after their undergraduate education is complete

Perceived lack of "exciting problems", perhaps due to the weak theoretical underpinnings of the field

Lack of a coherent communication system within the field which could promote research efforts and unify support for them

For the health of the field as a whole, these and other related problems must be addressed and ameliorated, but because of their nature this will take a good many years to accomplish, perhaps a generation.

As a beginning it would probably be useful to find support for a "centers of excellence" program for research and development in the AGIS and the spatial data handling fields. Such a program would identify a few universities, probably ones where a strong nucleus of research in related fields already exists, and would then provide them with additional support for moving more vigorously into the AGIS field. The workers in such centers should be drawn from a number of disciplines including mathematics, computer science, engineering, remote sensing, geography, the natural and social sciences which deal with spatially distributed data, and perhaps others.

Such centers cannot be created overnight; it will require years before they are functioning well and producing results. They will also require effective, perhaps even inspired leadership, given the scope of the AGIS and spatial data fields and the problems to be overcome. Such leaders will certainly have to be entrepreneurs of a high order.

Recommendations:

More support needs to be provided for research in the field.

Centers of excellence, devoted to research on automated geographic and automated spatial information systems, need to be created and supported on a long term basis.

Decision Making Institutions

The use of AGIS technology could be usefully integrated into the decision making processes of many institutions where it is not now employed.

AGIS's can be very effective in assisting decision makers in planning, management, policy making and related activities at many levels of government and in private industry. Unfortunately this is not widely enough appreciated. The result is inefficiency, higher than needed costs, failed development projects, waste of development funds, poor decisions, improper allocation of resources, unmet expectations and a wide range of other disbenefits. A good deal of work needs to be done in making decision makers aware of these matters, and specific suggestions are offered throughout this report on how to go about this.

In order to integrate AGIS technology into decision making it is necessary to identify what information is needed by the decision maker and what form the information should be in to be most useful and timely. Analyses of this kind, leading to AGIS use, are not often enough performed. Not enough thought has been given to devising means of integrating AGIS's into existing decision making, nor to devising AGIS's which are particularly responsive to decision making processes now in use. These efforts need to be made for many decision making institutions.

Where geographic data are used in present decision making processes, it would seem best, over time, to shift the basis of decision making to

data which are:

Automated rather than manually processed.

The least costly to gather

Lowest in resolution, though still suitable for the task

Lowest in volume or amount, though still suitable for use

Continuing studies of decision making need to be made so that AGIS use may be fully integrated into them, and successful examples need to be publicized.

Recommendations:

Continuing efforts need to be made to make decision makers aware of the usefulness of AGIS's in decision making and related processes.

Continuing studies need to be made of the best way of integrating AGIS's into decision making, and successes need to be made widely known.

Roles of Federal Agencies

Federal agencies have important roles to play in the development of the AGIS field.

The most immediate need from federal agencies is probably for some support for efforts like this present report: assessments of the situation in the AGIS field and support for planning toward improvement.

Another important need is for federal agency support for the NAS/NRC definitive study mentioned earlier in this report.

A number of federal agencies also have important interests in the AGIS field and in the creation of global data bases because of the nature of their missions; NASA, USGS, BLM, the Forest Service and other organizations probably

fall in this group. There are others, too. These agencies might play important roles in fostering the improvement of this technology.

Some of these federal roles would include sponsoring research, conducting their own research in areas of special interest to them, documenting and publishing information about their own applications of the technology, and joining with other agencies in concerted efforts in the field.

In performing these various roles, agencies will need to call on the expertise of many persons outside the government. For planning purposes, panels of experts might be formed; this could be done quite soon.

While cooperation between agencies would be quite helpful in these efforts, experience suggests it will not be easy to obtain.

Even to interest some agencies in AGIS's it may be necessary to tie the field to projects already of interest to the agency (such as Global Habitability in NASA).

New overtures may need to be made above the agency level (to the executive branch) or through congress if agency support cannot be obtained by other means.

Another approach might be to start with agencies or organizations outside the federal government (such as the United Nations or some other international organization), persuade such organizations of the case for AGIS's and have them approach the federal government.

Working with federal agencies to obtain support will require entrepreneurial skills of those in the AGIS field.

Recommendations:

Work should begin in a concerted way to obtain agency support for developing the AGIS field.

Agencies which are interested should be identified, to include the names of specific persons.

Sources of funds, ongoing related projects, future agency plans, and other important information should be gathered.

These efforts need to be coordinated, and useful information needs to be exchanged among those working in this direction.

University/Industry/Government Cooperation

No single sector of the economy has the means to provide all the support needed for the development of AGIS technology; cooperation among the sectors will be required.

In working toward the development of the AGIS field there are a variety of kinds of efforts needed. Some, such as education, are best done by the universities. Some, such as the development of new hardware and the marketing of new technology, are best done by industry. Some, such as large scale projects in the public interest, are best done by various levels of government.

It is important, for the sake of economy and efficiency, that some cooperation exist between the various sectors. Clearinghouse operations for information, research funding, used equipment, and other matters might be useful. Formal meetings between suitably chosen representatives from organizations within each of the three sectors might also be useful.

This cooperation will need to be worked at over a prolonged period.

Recommendations:

Continuing efforts should be made to foster cooperation between government, industry and the universities in support of development of the AGIS field.

System Implementation

AGIS's which meet all of a user's technical requirements may yet fail because of a poor implementation process.

The problem of implementing AGIS's is often a fatal one in the life cycle of the system. Many factors, often those related to the personalities and attitudes of the people involved, make this so. Many systems fail almost before they are installed because of insufficient attention to the overall implementation process.

Successful implementation requires a careful study of user needs; a careful design of the data base and of the hardware, software, management, institutional relationships and the human resources of the system; a careful specification of the system's requirements; perhaps a benchmark test of competing vendor systems; probably a pilot study if the application is not well worked out; early and thorough training of the users; follow up support during the early months or years of the use; and, probably above all else, close and continuing coordination between those supplying the system and the users. It is essential that the AGIS be "human engineered" and the process of implementation be sensitive to user resistance and attitudes.

It is also clear that many of the lessons learned in automating other business and government operations apply to the process of implementing AGIS's.

Recommendations:

In developing AGIS's it is extremely important that system implementation receive careful attention and all resources needed to make it successful.

People Problems and Political Problems

The creation and use of AGIS's inevitably result in situations from which problems can arise, problems which are people centered as opposed to technical. Political problems may also arise.

The automation of various kinds of human effort has created various people centered problems in the past and the increasing use of AGIS's is likely to have the same result. These potential problems, well known by now, need to be taken into account whenever AGIS's are installed and used.

Because of their power and the kinds of applications to which they are dedicated, AGIS's are also likely to become centers around which power will tend to aggregate. As a result, managers, decision makers, politicians, elected officials and others will become interested in and wish to have some control over AGIS's in their environment. Where they do not exist, those schooled in their capabilities will want them.

While the particular form of the problems cannot be known in advance, users should be aware of the possibilities involved. Moreover, as the number of AGIS's in use increases, these problems are likely to increase exponentially. Increasing attention will have to be given to them and to their solution.

It is possible that totalitarian governments will be especially interested in gaining control of AGIS's, as they are interested in controlling other forms of information and intelligence. In these and other instances, mere access to AGIS's may become a political issue.

Data sharing will present problems in cases where a country or a government perceives itself at a military, political or economic disadvantage because of sharing data. Probably only political agreements will ameliorate this kind of problem for any global data base system.

Recommendations:

Those responsible for making policy about AGIS's, decision makers generally, and those installing and using AGIS's need to be aware of these potential problems and devote the needed resources to ameliorating them.

Pricing and Profits in the AGIS Field

Both private industry and government have some influence on pricing in the AGIS field and the influence of their actions will determine how rapidly some facets of AGIS technology will develop.

In many areas the development of new AGIS technology will take place because of market forces and competitive pressures, especially where products can be marketed to customers beyond just AGIS users. In these cases, because of trade secrets and proprietary information, concerted research and development efforts cannot be mounted, and may not be necessary. If the market is large enough and competition is keen, prices can be expected to fall and performance to rise. Computer hardware development conforms to this model.

Where manufacturers do not see large sales and potential profits, development may be slower, even though products would be of great utility. Where the products contribute to the general good, the government may support the research and development process. Landsat was created by such an effort and might not exist were that not so.

Unfortunately, AGIS's are often viewed as having only marginal value by potential users, and since a system may cost \$250,000, purchase is seen as a major commitment, even though the benefits may far outweigh the costs.

This is a considerable problem when new technology is being introduced to a wider user group.

It may be that in the near term government ought to subsidize the development of some parts of AGIS technology, and in so doing help keep the price of the technology low enough to be attractive to a wider group of users.

When government does this and the technology begins to be used, there is a temptation to rapidly shift the costs to the users. In the near term this should be resisted. There is a learning curve associated with the use of technology, and an inevitable lag time and technology diffusion time required before obtaining the wide use which is required for creating reasonable or low prices (the use of computers is a good illustration of this). The government should be prepared to support the development of such a technology until market forces can provide profits sufficient that private industry can take over that task.

Some facets of AGIS technology may fit this profile: important to the general good, not being developed rapidly enough by private industry, suitable for government support of research and development. These facets may justify government "pump priming" or government acceptance of joint research efforts by groups of firms, or tax benefits for particular types of research and development, or other devices.

Recommendations:

Where private industry is not developing needed AGIS technology which is important to the public good the government should consider supporting research and development by various means available to it.

Government may also need to continue support in ways which keep prices low enough to encourage adoption of this technology by users who could not afford the "real" costs of the technology.

Consultants

Consultants are needed in the AGIS field and there may not be enough competent consultants available to meet the anticipated future growth in the field.

It is characteristic of new and developing fields that real experts on the technology are few and often widely scattered geographically, making it difficult for those wanting to use the technology to obtain good advice on how to proceed. The AGIS field is in this situation at present.

Under these circumstances those seeking to develop their own AGIS capabilities may go ahead without competent advice, may seek the advice of persons already known to them who may have some familiarity with the field, may undertake their own studies, may seek the advice of a consultant or an organization that provides consulting, or may adopt some other strategy to meet their needs.

Competent consultants can provide a tremendous service in a rapidly developing field like AGIS's by making up-to-date, sound advice available to their clients and thus helping in the economical, rapid and effective use of the technology.

Unfortunately, there are probably just not enough competent consultants now in the AGIS field to meet the growth which can be anticipated in the years just ahead. It is possible, even likely, that this situation will retard the growth of the field and the implementation of this very valuable technology. Potential users will go ahead without advice, or with incompetent advice, and the resulting failures will inhibit further trials for some time.

While there is no clear solution to this problem, some actions can be taken to ameliorate it. Short courses on AGIS technology are now offered and where they are sound and properly conducted, attendees may receive some

of the benefits that a consultant might provide; universities, research centers and professional organizations may need to conduct more such courses in the future. Specially written textbooks, which include case studies, applications documentation and the like, may also partly fill the need; it may be that professional organizations should take the lead in the preparation of such materials, perhaps incorporating standard practice in the process. Traveling lecturers who are expert in the field may need to be supported. Special institutes, sponsored by various agencies or organizations, and involving hands on use of the technology and site visits to AGIS users, probably need to be more widely used. Other means should also be explored.

This area is one which would probably benefit considerably from the activities of a professional organization dealing with AGIS's and related matters.

Recommendations:

In the absence of sufficient competent consultants in the AGIS field, a wide range of educational and communication efforts need to be undertaken to ensure that reliable information about the field is widely available.